

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
21 March 2002 (21.03.2002)

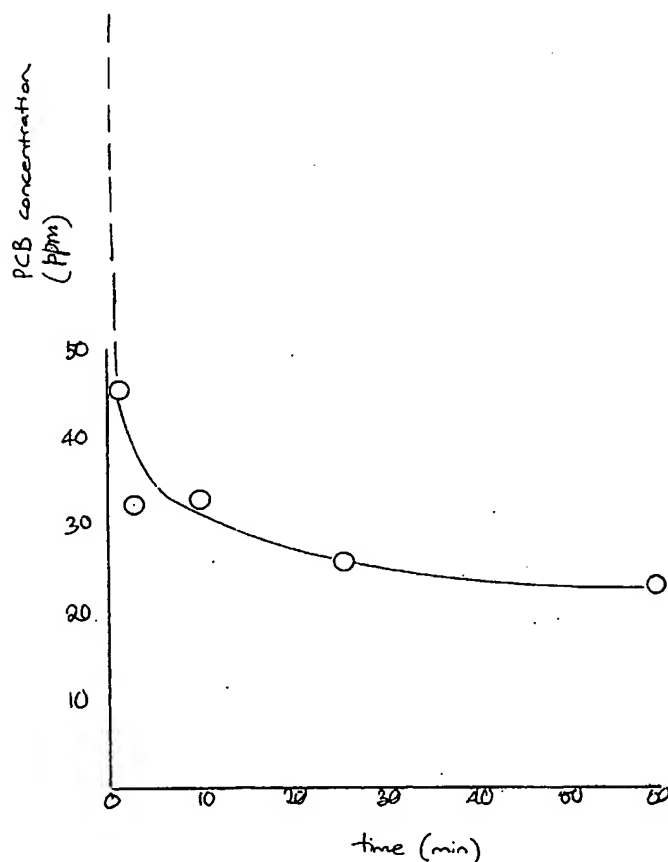
PCT

(10) International Publication Number  
**WO 02/22252 A1**

- (51) International Patent Classification<sup>7</sup>: **B01J 19/10**
- (21) International Application Number: **PCT/AU01/01164**
- (22) International Filing Date:  
13 September 2001 (13.09.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
PR 4871 13 September 2000 (13.09.2000) AU
- (71) Applicant (for all designated States except US): **COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION [AU/AU]**; Limestone Avenue, Campbell, Australian Capital Territory 2601 (AU).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **COLLINGS, Anthony, Francis [AU/AU]**; 5 Robin Avenue, Turramurra, New South Wales 2074 (AU).
- (74) Agent: **GRIFFITH HACK**; GPO Box 4164, SYDNEY, New South Wales 2001 (AU).
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian

[Continued on next page]

(54) Title: PROCESS FOR TREATING A SOLID-LIQUID MIXTURE



(57) Abstract: A process for treating a solid-liquid mixture by cavitation has been developed to decompose at least some contaminant associated with the solid particles, the contaminant either being adsorbed into the pores of the solid or onto the surface of the solid particles. The process includes the step of subjecting the mixture to cavitation such that a portion of the contaminant is chemically decomposed. Typically the chemical decomposition occurs at the surface of the solid particles, although the process can also occur to some extent within the pores near the surface of the solid material being treated. Typically the cavitation process is an ultrasonic treatment step, although other cavitation processes are applicable, for example high shear mixing. The cavitation effect is capable of achieving physico-chemical changes at the particle surfaces. The localised high temperatures on bubble collapse (as high as 5000K) can decompose contaminant substances such as PCB and other hazardous materials including polybrominated biphenyl (PBB), organochloride and organophosphate compounds, pesticides and the like. One of the advantages of the treatment process is that the decomposition products are quenched quickly to the temperature of the bulk fluid (at, for example, 50°C) which avoids the reformation of the PCB or the formation of undesirable side reaction products such as dioxins.



patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

— *with international search report*

**PROCESS FOR TREATING A SOLID-LIQUID MIXTURE****Field of the Invention**

The present invention relates to a process for the decomposition of contaminant substances. The method can be applied to decontaminate soils and other substrates containing polychlorinated biphenyl (PCB) compounds in domestic, municipal or industrial applications and will primarily be described with reference to this context. It should be remembered, however, that the invention has broader use in the decomposition of all manner of hazardous materials including polybrominated biphenyl (PBB), organochlorides and organophosphate compounds, pesticides and the like.

**Background Art**

Polychlorinated biphenyls (PCB compounds) were first discovered to be environmental pollutants in 1966. They have been found throughout the world in water, solid sediments, and bird and fish tissue. There are some 209 different PCB compounds available, made by substituting from 1 to 10 chlorine atoms onto a biphenyl aromatic structure. PCB compounds have very high chemical, thermal and biological stability, and a low water solubility and vapour pressure. While these useful properties contributed to their widespread use, those same properties allowed these compounds to be accumulated in the environment.

The manufacture of PCB compounds was discontinued in the United States in 1979, although these compounds continue to enter the environment from discarded electrical equipment, etc. PCB concentrations of 1-2ppm are normally the desired maxima, and levels of 10-50ppm in agricultural soils, clays or marine sediments are

considered hazardous. The dense and hydrophobic nature of PCB compounds ensures that their accumulation in river sediment is commonplace, leading to bioaccumulation in bottom dwellers and fish thus leading to entry into the human food chain. PCB compounds can reduce human disease resistance, and increase the incidence of rashes, liver ailments and headaches. Similarly, pesticides can have serious health effects on humans and animals.

Numerous investigations of ways to degrade PCB compounds and pesticides have been carried out. At present there are no widely accepted methods for the large scale remediation of water or soils contaminated with PCB compounds or pesticides. The decomposition of PCB and organochloride compounds can be effected by high temperature incineration at a typical temperature of 1300°C but the gaseous products must be quenched quickly to avoid the reformation of the PCB or the formation of undesirable side reaction products such as dioxins at 800-900°C. Such a process is complicated and with variable or uncertain outcomes. Biodegradation with microorganisms and chemical treatment are methods which require lengthy treatment periods. Photocatalytic (UV) degradation of contaminated soil-water systems has also been tried but is also slow.

Ultrasound is known in the art for inducing chemical reaction processes in liquids, a field known as sonochemistry. The propagation of ultrasonic waves in a liquid generates cavitation bubbles. These bubbles implode and produce micro-regions of extreme conditions. Estimated temperatures within these micro-regions range from 2000-5000K in aqueous solution. In US5498431 a process is described for decontaminating particulate surfaces by the use of ultrasound to firstly release

mycotoxins from the particulates into an aqueous liquid followed by a chemical reaction breakdown of the contaminants by ultrasound when in the liquid. The cavitation from the ultrasound leads to a sonochemical breakdown reaction of the mycotoxin contaminants when in the aqueous liquid. In W096/20784 a method of chemical reaction catalysis in a liquid is described which is facilitated by ultrasonic cavitation. The cavitation is aided by the presence of solid particles as a surface for 'seeding' the cavitation bubbles prior to their separation from the solid particles whereupon the bubbles cavitate (implode) in the liquid medium.

Ultrasound has been used to decompose PCB compounds that are dissolved in an aqueous solution. However, because of their low solubility, the concentration of PCB compounds in aqueous solution is very low when compared with that found adsorbed onto solids, river sediment and the like, so that such an aqueous treatment technique is largely ineffective.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

#### **Summary of the Invention**

In a first aspect the present invention provides a process for treating a mixture of a solid and a liquid to decompose a contaminant associated with the solid, said process including the step of subjecting the mixture to cavitation wherein at least a portion of the contaminant is chemically decomposed, the chemical decomposition occurring at or near a surface of the solid.

Such process can provide an improved technique for the decomposition of contaminant substances by providing for localised high temperatures followed immediately by a quenching of the decomposition products (ie. by the liquid) thereby avoiding the reformation of the substance or the formation of undesirable side reaction products at certain temperatures. The technique can effectively treat contaminated solid particles at their surface where the concentration of contaminants is at its highest when compared with the aqueous phase.

In the prior art processes for the chemical decomposition of a contaminant by the use of cavitation, a physical separation of the contaminant from a substrate material into a liquid occurs so that sonochemical reactions can occur in the liquid. In the present process a physical separation of a contaminant from a substrate into a surrounding liquid is not required and the contaminant is present at or near the surface of the solid. US5498431 and WO96/20784 disclose only that chemical decomposition occurs in the surrounding liquid.

Preferably the cavitation process is effected by an ultrasonic treatment process using ultrasonic source equipment such as ultrasonic plates, probes, baths or other chambers.

Preferably the process also includes the step of mixing the solid and liquid whereby the solid is substantially suspended in the liquid to increase exposure of the mixture to cavitation.

Preferably the solid includes mineral and/or organic matter. Most preferably the solid includes one or more materials such as silica, clay, carbonaceous material, activated carbon or calcium carbonate.

In a second aspect the present invention provides a process for treating a mixture of a solid and a liquid to decompose a contaminant associated with the solid, said process including the step of subjecting the mixture to  
5 cavitation wherein at least a portion of the contaminant is chemically decomposed and wherein at least some of the solid serves to catalyse the decomposition.

Preferably in this second aspect the chemical decomposition occurs at or near a surface of the solid.

10 Preferably the other process steps of the second aspect are as defined in the first aspect.

In a third aspect the present invention provides a process for treating and decomposing a contaminant in a liquid which includes the contaminant, the process  
15 including the steps of:

- adsorbing the contaminant on a solid; and
- subjecting a mixture of at least some of the solid and at least some of the liquid to cavitation such that at least a portion of the contaminant associated with the  
20 solid is chemically decomposed at or near a surface of the solid.

Preferably the process steps of the third aspect are as defined in the first aspect.

## 25 **Brief Description of the Drawings**

Notwithstanding any other forms which may fall within the scope of the present invention, a preferred form of the invention will now be described, by way of example only, with reference to the accompanying drawings in  
30 which:

Figure 1 shows some experimental results for the decomposition of a PCB located on a silica particulate substrate as a function of time; following the treatment

of aqueous particulate suspensions in accordance with an embodiment of the invention.

Figure 2 shows some other experimental results for the decomposition of a PCB at a higher initial concentration located on a silica particulate substrate as a function of time; following the treatment of aqueous particulate suspensions in accordance with an embodiment of the invention.

Figure 3 shows some other experimental results for the decomposition of a PCB located on a silica particulate substrate as a function of time; following the treatment of aqueous particulate suspensions in accordance with an embodiment of the invention.

Figure 4 shows some other experimental results for the decomposition of a PCB located on a calcium carbonate particulate substrate as a function of time; following the treatment of aqueous particulate suspensions in accordance with an embodiment of the invention.

Figure 5 shows some experimental results for the decomposition of a pesticide (Chlordane) located on a silica particulate substrate as a function of time; following the treatment of aqueous particulate suspensions in accordance with an embodiment of the invention.

Figure 6 shows some experimental results for the decomposition of a pesticide (DDT) located on a silica particulate substrate as a function of time; following the treatment of aqueous particulate suspensions in accordance with an embodiment of the invention.

#### **Modes for Carrying out the Invention**

A process for treating a solid-liquid mixture by cavitation has been developed to decompose at least some contaminant associated with the solid particles, the



contaminant either being adsorbed into the pores of the solid or onto the surface of the solid particles.

The process includes the step of subjecting the mixture to cavitation such that a portion of the  
5 contaminant is chemically decomposed. Typically the chemical decomposition occurs at the surface of the solid particles, although the process can also occur to some extent within the pores near the surface of the solid material being treated. In the preferred embodiment the  
10 cavitation process is an ultrasonic treatment step, although other cavitation processes are applicable, for example high shear mixing.

Under the influence of ultrasound, the formation of a vapour bubble (as distinct from one formed from dissolved  
15 gases) occurs when stress in the liquid (due to the negative pressure produced during the expansion cycle of a sound wave) exceeds the tensile strength of the liquid. The stress at a solid-liquid boundary, due to the presence of an ultrasonic field, is much greater than in the bulk  
20 of a liquid. The likelihood of a vapour bubble forming at the solid-liquid boundary is around twice that in the body of liquid. This applies to both solid particle suspensions as well as to the walls of a vessel. The smaller particles are more likely to support vapour bubble  
25 nuclei because of their high surface area and surface free energy.

Large amounts of energy are released from the cavitation collapse of vapour bubbles at or near the surface of the solids. The manner of the collapse near a  
30 surface takes the form of a high velocity jet directed at that surface. This effect is capable of achieving physico-chemical changes at the particle surfaces.

The inventor has surprisingly discovered that the localised high temperatures on bubble collapse (as high as 5000K) can decompose contaminant substances such as PCB and other hazardous materials including polybrominated biphenyls (PBB), organochloride and organophosphate compounds, pesticides and the like. One of the advantages of the treatment process is that the decomposition products are quenched quickly to the temperature of the bulk fluid (at, for example, 50°C) which avoids the reformation of the PCB or the formation of undesirable side reaction products such as dioxins.

In the preferred embodiment the solid-liquid mixture being treated by such a process can also be mixed by means of an impeller or similar stirring device in a mixing vessel to cause the solid-liquid mixture to become substantially suspended. This can maximise the exposure of the particle surfaces in the mixture to cavitation. It is also possible that the mixture can be stirred simultaneously with insonation or as separate steps.

Typically the solid particles are mineral and/or organic matter for example silica (sand), calcium carbonate, carbonaceous matter including activated carbon, clay or soils and sediments containing organics and/or mixtures thereof.

The role of the solid substrate can also be to catalyse the decomposition depending upon the material chosen. The substrate can in fact catalyse the rate and the extent of the decomposition reaction. Such substrate materials may include titanium dioxide, for example (a known photocatalytic material).

The porosity of the substrate can also influence the quantity of PCB available for surface or near surface reaction. Very adsorptive or porous substrates such as

activated carbon or charcoal can adsorb a large quantity of a contaminant substance and make this material available at the surface for reaction.

5 The source of the ultrasound can be any suitable device which can be used to deliver sound waves of sufficient power and intensity, typically an ultrasonic bath, plate or probe source.

10 In use the process can provide an improved technique for the decomposition of PCB and other hazardous substances by providing a localised high temperatures followed immediately by a quenching of the decomposition products thereby avoiding the reformation of the substance or the formation of undesirable side reaction products. The technique can effectively treat contaminated solid  
15 particles by a surface reaction which is where the concentration of contaminants is highest when compared with the aqueous phase.

The process can also be applied to situations where a contaminated liquid flow requires effective treatment.  
20 Normally the use of ultrasound to treat low levels of PCB or pesticides etc when dissolved in a liquid stream is an ineffective process. Large volumes of fluid having a low concentration of contaminant are not able to be efficiently processed. As an alternative, the PCB or  
25 other contaminant can be adsorbed onto a solid substrate and the substrate then subjected to a cavitation step to effect the chemical decomposition of the much more concentrated contaminant. If a high surface area reusable material such as activated carbon or clay solids was used,  
30 the process can be repeatedly applied to a liquid stream using the same recycled solid materials.

Whilst the invention has been described with reference to a number of preferred embodiments it should

be appreciated that the invention can be embodied in many other forms.

### Experimental Examples

5 The following experimental examples show the reduction of adsorbed PCB concentrations on solid particles following ultrasonic treatment in an aqueous pulp.

10 Calcium carbonate and silica (sand) solids were mixed separately with a PCB compound which had been separately dissolved in acetone to form a solution. The PCB compound selected was available under the trade name ARACLOR 1260. The mixture was then evaporated to dryness and the PCB then became surface adsorbed onto the solids. A 100g quantity of these solids and an equivalent weight of water  
15 were then agitated to produce an aqueous slurry batches of which were experimentally subjected to ultrasound at a frequency of 20kHz and a power input of 170W. The residual PCB remaining on the solids as a function of time was measured by gas chromatography.

20 Figure 1 depicts the reduction in measured PCB on silica solids following extended periods of sonication up to 60 minutes. The initial concentration of PCB was around 8ppm and was reduced to around 2ppm after 60 minutes, representing around 75% decomposition.

25 Figure 2 depicts the reduction in measured PCB on silica solids following extended periods of sonication up to 60 minutes. The initial concentration of PCB was above 50ppm, and was reduced to around 24ppm after 60 minutes representing more than 50% decomposition.

30 Figure 3 depicts the reduction in measured PCB on silica solids following periods of sonication up to 10 minutes. The initial concentration of PCB was around

60ppm and was reduced to around 35ppm after 10 minutes representing around 45% decomposition.

Figure 4 depicts the reduction in measured PCB on calcium carbonate solids following periods of sonication up to 10 minutes. The initial concentration of PCB was around 100ppm and was reduced to around 65ppm after 10 minutes representing around 35% decomposition.

The following experimental example shows the reduction of adsorbed DDT and chlordane concentrations on solid particles following ultrasonic treatment in an aqueous pulp.

Silica (sand) solids were mixed separately with DDT and chlordane which had been separately dissolved in acetone to form a solution. Each mixture was then evaporated to dryness, the respective pesticides then being surface adsorbed onto the solids. A 100g quantity of these solids and an equivalent weight of water were then agitated to produce an aqueous slurry batches of which were experimentally subjected to ultrasound at a frequency of 20kHz and a power input of 170W. The residual DDT and chlordane remaining on the solids as a function of time was measured by gas chromatography.

Figure 5 depicts the reduction in measured chlordane and Figure 6 the reduction in measured DDT concentration on silica solids following extended periods of sonication up to 30 minutes. The initial concentration of DDT was around 715ppm and was reduced to around 185ppm after 30 minutes, representing around 74% decomposition. In the case of the chlordane, the initial concentration of chlordane was around 715ppm and was reduced to around 270ppm after 30 minutes, representing around 62% decomposition.

## CLAIMS

1. A process for treating a mixture of a solid and a liquid to decompose a contaminant associated with the solid, said process including the step of subjecting the mixture to cavitation wherein at least a portion of the contaminant is chemically decomposed, the chemical decomposition occurring at or near a surface of the solid.
2. A process for treating a mixture as claimed in claim 1 wherein the cavitation process is effected by an ultrasonic treatment process.
3. A process for treating a mixture as claimed in claim 1 or claim 2 also including the step of mixing the solid and liquid whereby the solid is substantially suspended in the liquid to increase exposure of the mixture to cavitation.
4. A process for treating a mixture as claimed in any one of the preceding claims wherein the solid includes mineral and/or organic matter.
5. A process for treating a mixture as claimed in any one of the previous claims wherein the solid includes one or more materials such as silica, clay, carbonaceous material, activated carbon or calcium carbonate.
6. A process for treating a mixture of a solid and a liquid to decompose a contaminant associated with the solid, said process including the step of subjecting the mixture to cavitation wherein at least a portion of the

contaminant is chemically decomposed and wherein at least some of the solid serves to catalyse the decomposition.

7. A process as claimed in claim 6 wherein the chemical decomposition occurs at or near the surface of the solid.
8. A process as claimed in claim 6 or claim 7 wherein the process steps are as defined in any one of claims 2 to 5.
9. A process for treating and decomposing a contaminant in a liquid which includes the contaminant, the process including the steps of:
- adsorbing the contaminant on a solid;
  - subjecting a mixture of at least some of the solid and at least some of the liquid to cavitation such that at least a portion of the contaminant associated with the solid is chemically decomposed at or near a surface of the solid.
10. A process as claimed in claim 9 wherein the process steps are as defined in any one of claims 2 to 5.
11. A process for treating a mixture of a solid and a liquid, said process being substantially as herein described with reference to the accompanying examples.
12. A process for treating and decomposing a contaminant in a liquid flow which includes the contaminant, said process being substantially as herein described with reference to the accompanying examples.

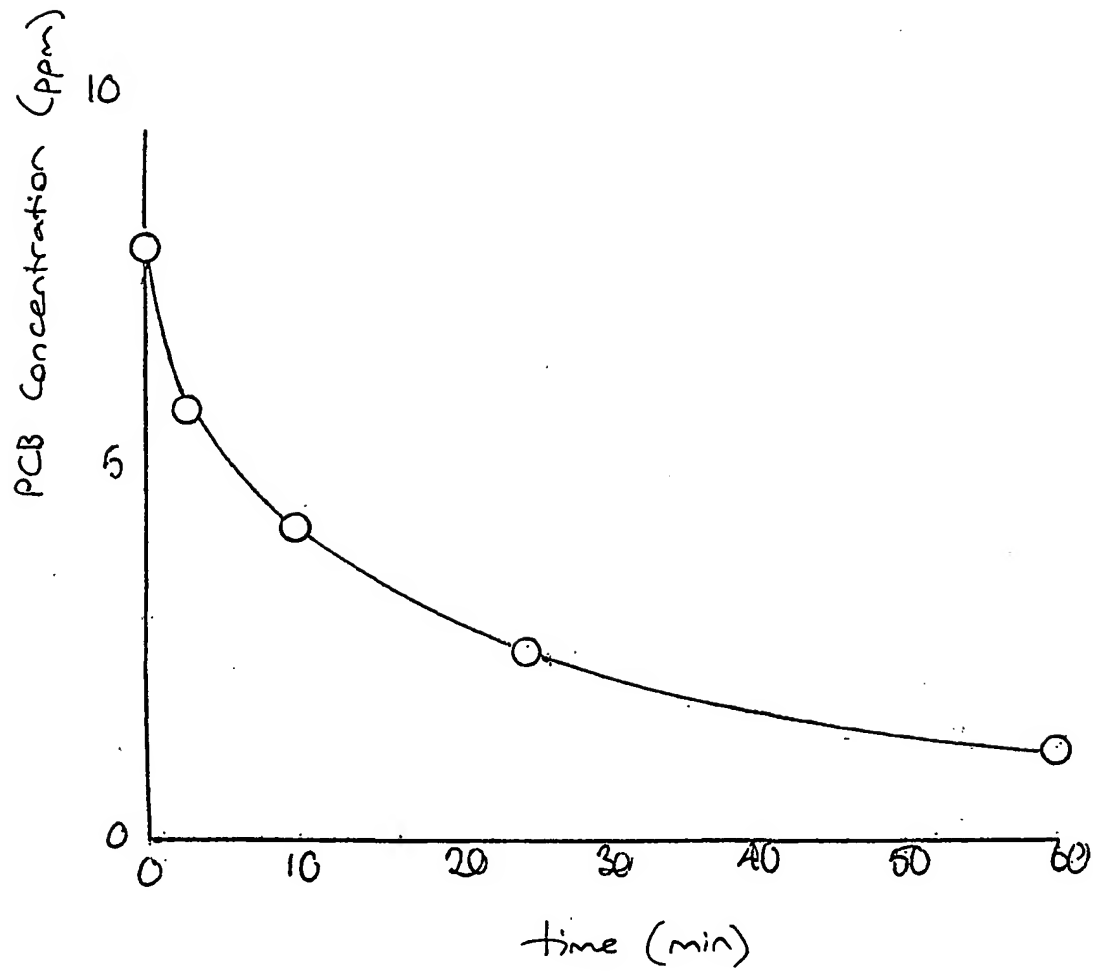


FIG. 1



2/6

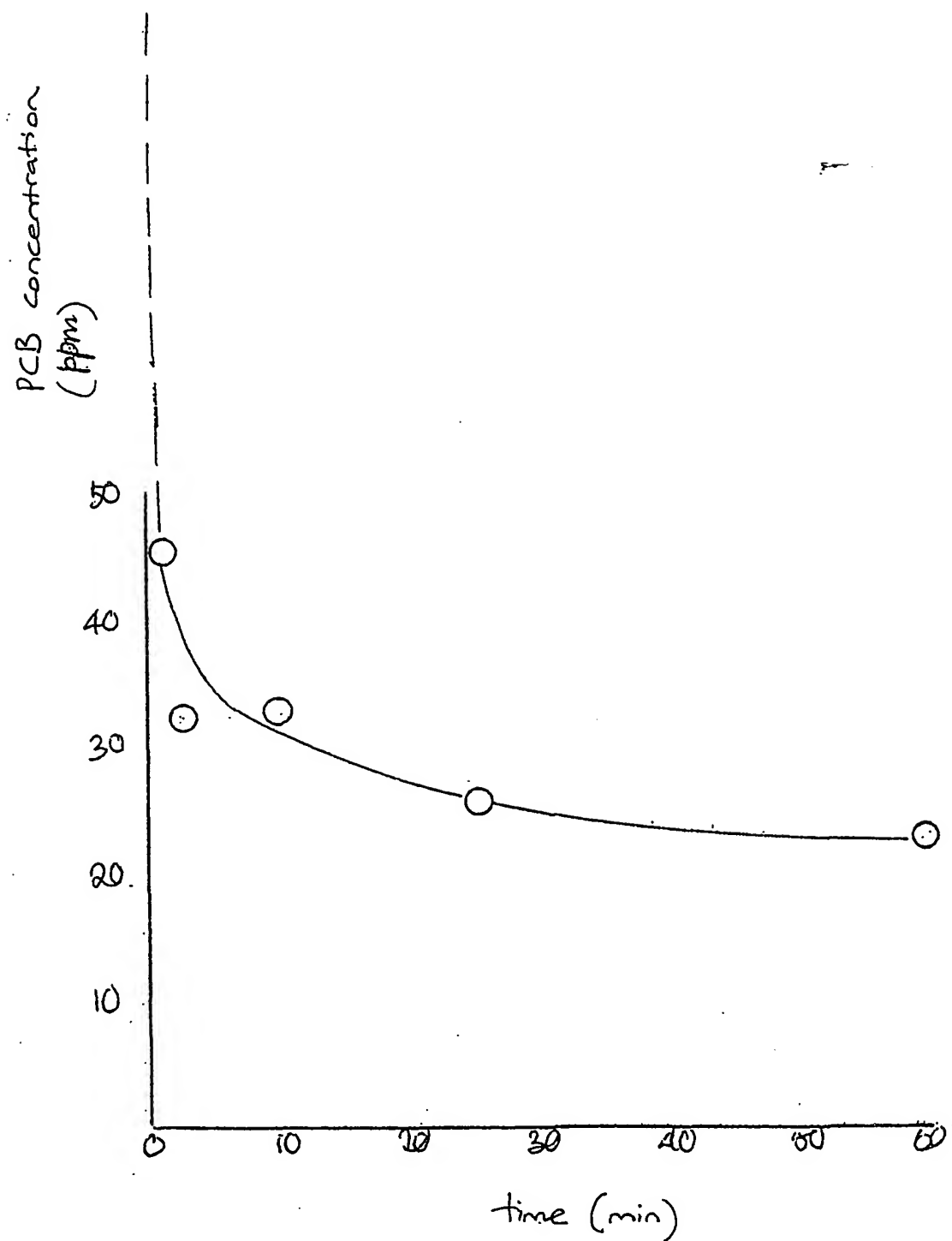


FIG. 2

3/6

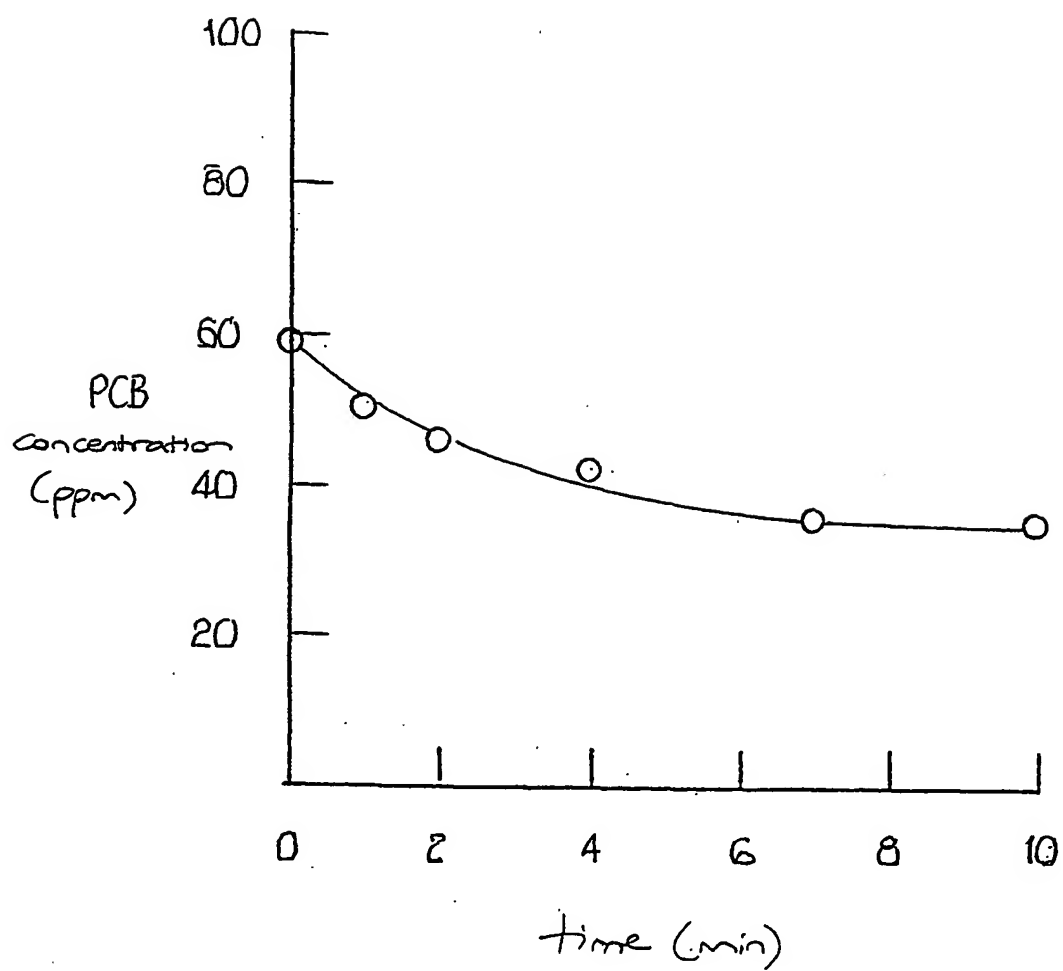


FIG. 3

4/ 6

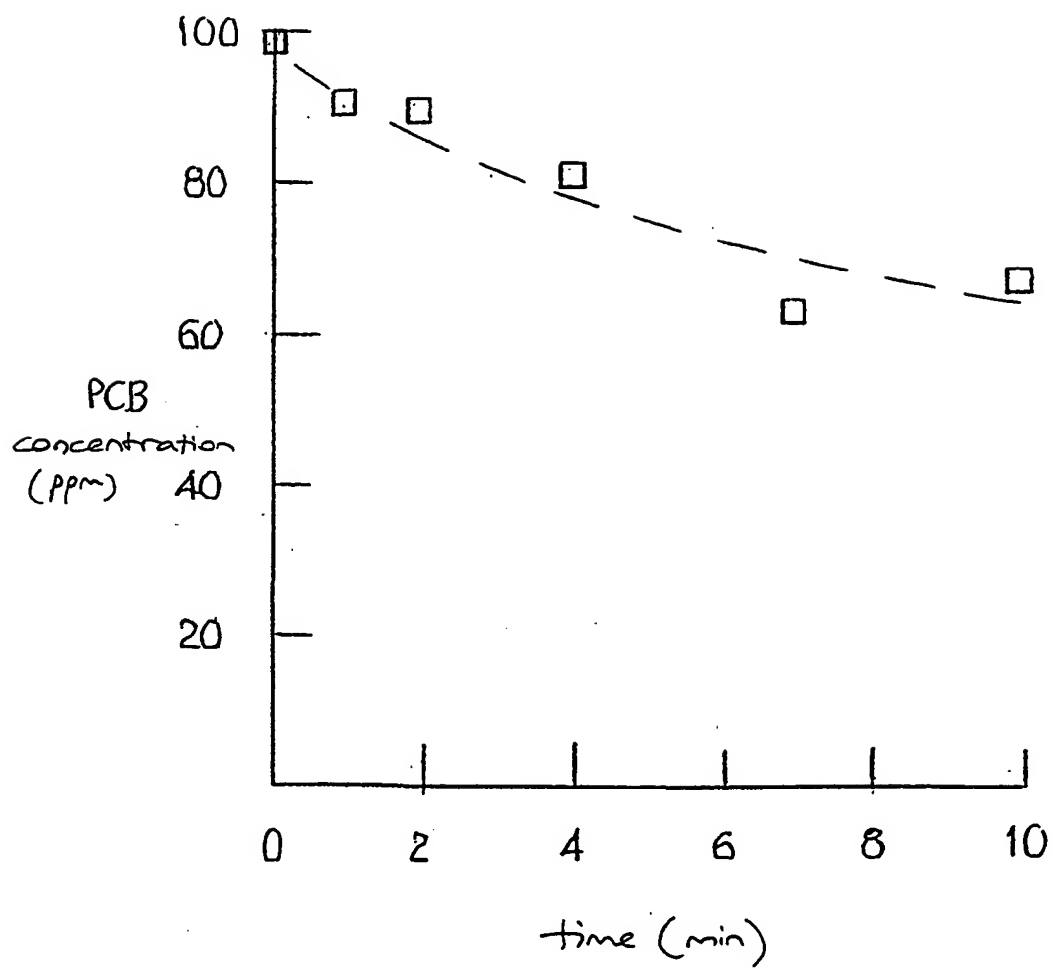


FIG. 4

5/6

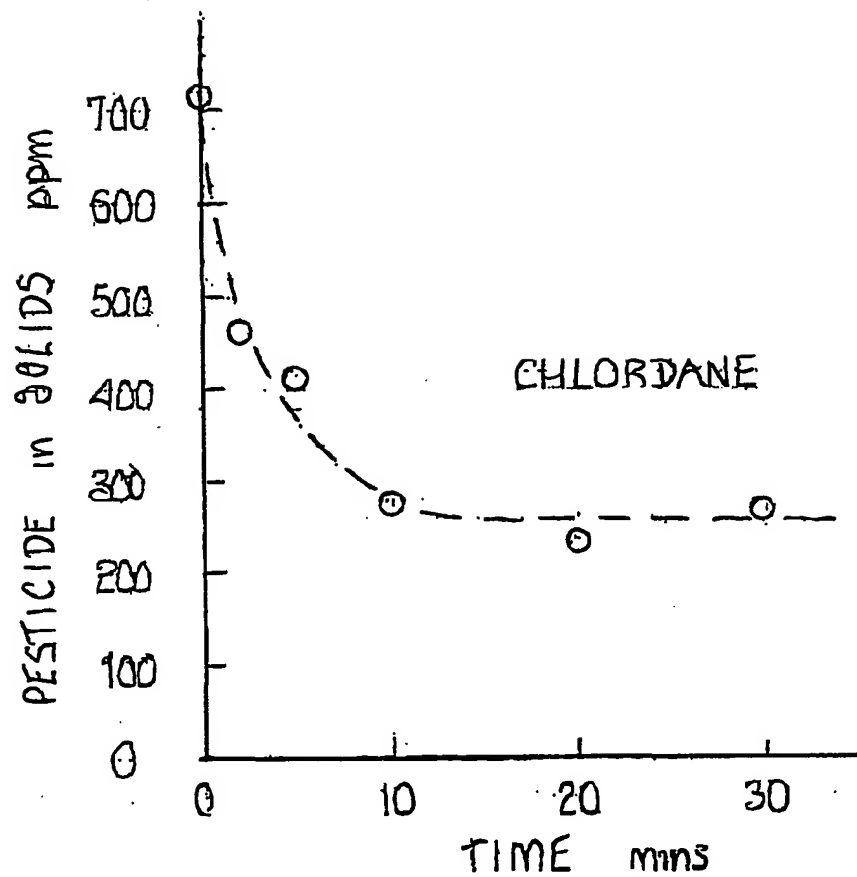


FIG. 5

6/6

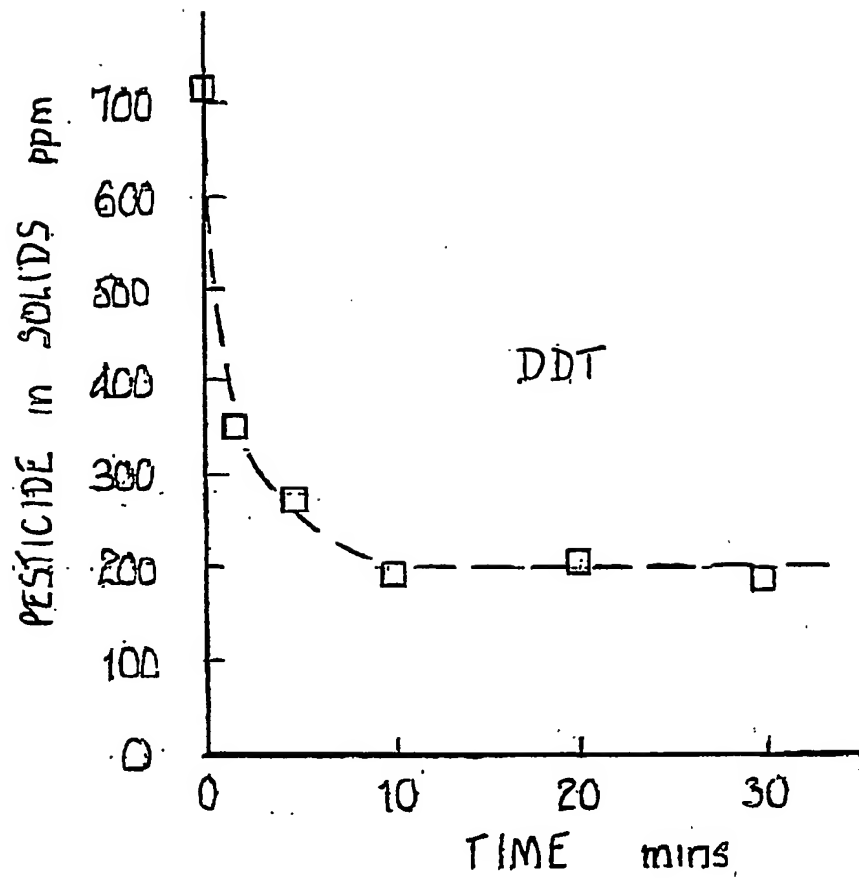


FIG. 6

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU01/01164

## A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. <sup>7</sup>: B01J 19/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC (7): B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6117334 (COURY et al.), 12 September 2000 Whole document	1-12
X	WO 00/17109 (CNAM), 30 March 2000 Whole document	1-12
X	EP 0529845 (EKOKEM OY AB), 3 March 1993 Whole document	1-12

☒ Further documents are listed in the continuation of Box C ☐ See patent family annex

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance  
 "E" earlier application or patent but published on or after the international filing date  
 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  
 "O" document referring to an oral disclosure, use, exhibition or other means  
 "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
 "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
 "&" document member of the same patent family

Date of the actual completion of the international search  
8 November 2001

Date of mailing of the international search report

19 NOV 2001

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
E-mail address: pct@ipaaustralia.gov.au  
Facsimile No. (02) 6285 3929

Authorized officer

ADRIAN GILLMORE

Telephone No : (02) 6283 2125

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5053141 (LAIHO), 1 October 1991 Whole document	1-12
X	US 4401131 (LAWSON), 30 August 1983 Whole document	1-12